Hydrogen Pathway Cost Distributions

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Outline

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- Cost Distribution Objective
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- H2A Influence
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Hydrogen R&D Cost Goal

- Goal is pathway independent
- Developed through a well defined, transparent process
- Consumer fueling costs are equivalent or less on a cents per mile basis
- Evolved gasoline ICE and gasoline-electric hybrids are benchmarks
- R&D guidance provided in two forms
  - Evolved gasoline ICE defines a threshold hydrogen cost used to screen or eliminate options which can't show ability to meet target
  - Gasoline-electric hybrid defines a lower hydrogen cost used to prioritize projects for resource allocation

Hydrogen R&D Cost Goal

Mechanics

$$\text{H2 Cost (\$ / gge)} \leq \text{(EIA Gasoline Price in 2015)} \left[\frac{\text{Fuel Economy H2FCV}}{\text{Fuel Economy Competitive Vehicle}} \right]^{1}$$

Input	Value	Source
Gasoline price projection for 2015	$1.26 / gal (untaxed, 2005 $)	EIA Annual Energy Outlook, 2005
Ratio of FCV fuel economy to evolved gasoline ICE	2.40	NRC H2 Economy Report
Ratio of FCV fuel economy to gasoline hybrid	1.66	NRC H2 Economy Report

Results

- **Hydrogen Threshold Goal = $3.00 / gge**
- **Hydrogen Prioritization Goal = 2.00 / gge**

[1] Ratio of FCV fuel economy to competitive vehicle

Cost Distribution Objective

- Ensure that pathway component cost goals are consistent with the pathway-independent cost goal
  1. Develop a set of component goals via a transparent process
  2. Initiate discussions with other Tech Teams to test goal feasibility
  3. Mediate cross-Tech Team issues

Overview

- Central production pathways
- Common point in time (2015)
- All pathways must meet global goal
- Components that reside in multiple pathways must have same goal
- Any “feedstock” reductions are due to efficiency improvements
- Use H2A as a basis
  - Data
  - Granularity

Common Components

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$1.89	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	$2.54	$8.57

H2A:
Input Assumptions, Production

- Production units are scaled so that each production scenario meets the same demand
- Production units are close enough in size to original analysis unit (or multiples of original analysis unit) that scaling factors are not required
- Each production scenario has a 330,000 kg/day capacity and serves 215 stations
- Production unit scaling is based on plant production, not plant capacity

H2A:
Input Assumptions, Delivery

- Assumes a 1,650,000 population, based on Cincinnati, OH
- Assumes a 50% vehicle penetration
- Assumes an urban population
- Assumes 2 cases: pipeline delivery and liquid truck delivery
- Assumes a city area of 672 sq miles
- Assumes a distance of 100 km from production to city
- The model calculates that two trunk rings are required

H2A:
Assumptions Embedded in Model

- All central plants produce hydrogen at 300 psi
- Liquefaction or pipeline compression included in delivery
- Delivery costs based on 98% H2
- Delivery costs based on 5,000 psi dispensing

Approach

- Normalize total pathway costs to the global goal
- Harmonize the costs for components that are common between pathways
- Two mechanisms evaluated:
  - "Least Economic" basis
  - "Most Economic" basis

“Least Economic” Basis

- Uses highest cost pathway as a basis
- For base pathway, reduce all component costs by a constant % to meet goal
- Apply new component costs to the other delivery mode pathway
- Apply new delivery costs to other pathways

H2A Starting Point

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$1.89	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	$2.54	$8.57

Identify Highest Cost Pathway

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$1.89	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	**$0.01**	**$6.03**	**$2.54**	**$8.57**

Normalize To Global Goal

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
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Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$1.89	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	**$0.00**	**$2.11**	**$0.89**	**$3.00**

Apply Costs To Other Delivery

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$1.89	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	**$0.00**	**$2.11**	**$0.89**	**$3.00**
Central Wind Electrolysis Liquid Distribution	**$0.00**	**$2.11**	**$0.89**	**$3.00**

Delivery Goals Not Uniform

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	**$1.89**	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	**$2.54**	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	**$1.89**	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	**$2.54**	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	**$1.89**	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	**$2.54**	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.00	$2.11	**$0.89**	$3.00
Central Wind Electrolysis Liquid Distribution	$0.00	$2.11	**$0.89**	$3.00

Apply New Delivery Goals

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	**$0.89**	$2.46
Biomass Central Liquid Distribution	$0.70	$0.87	**$0.89**	$2.46
SMR Central Pipeline Distribution	$1.13	$0.37	**$0.89**	$2.39
SMR Central Liquid Distribution	$1.13	$0.37	**$0.89**	$2.39
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	**$0.89**	$2.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	**$0.89**	$2.23
Central Wind Electrolysis Pipeline Distribution	$0.00	$2.11	**$0.89**	$3.00
Central Wind Electrolysis Liquid Distribution	$0.00	$2.11	**$0.89**	$3.00

All Pathways Meet Goal

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$0.89	**$2.46**
Biomass Central Liquid Distribution	$0.70	$0.87	$0.89	**$2.46**
SMR Central Pipeline Distribution	$1.13	$0.37	$0.89	**$2.39**
SMR Central Liquid Distribution	$1.13	$0.37	$0.89	**$2.39**
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$0.89	**$2.23**
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$0.89	**$2.23**
Central Wind Electrolysis Pipeline Distribution	$0.00	$2.11	$0.89	**$3.00**
Central Wind Electrolysis Liquid Distribution	$0.00	$2.11	$0.89	**$3.00**

“Most Economic” Basis

- Uses lowest cost pathway as a basis
- For base pathway, reduce all component costs by a constant % to meet goal
- Apply new component costs to the other delivery mode pathway
- Apply new delivery costs to other pathways
- Reduce other pathway production costs to meet goal

H2A Starting Point

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.28	$1.06	$1.89	$3.23
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	$2.54	$8.57

Identify Lowest Cost Pathway

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	**$0.28**	**$1.06**	**$1.89**	**$3.23**
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	$2.54	$8.57

Normalize To Global Goal

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
Coal Central No Sequestration Pipeline Distribution	**$0.26**	**$0.99**	**$1.75**	**$3.00**
Coal Central No Sequestration Liquid Distribution	$0.28	$1.06	$2.54	$3.88
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	$1.89	$7.92
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	$2.54	$8.57

Apply Costs To Other Delivery

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	$1.89	$3.45
Biomass Central Liquid Distribution	$0.70	$0.87	$2.54	$4.10
SMR Central Pipeline Distribution	$1.13	$0.37	$1.89	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	$2.54	$4.04
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Delivery Goals Not Uniform

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
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SMR Central Pipeline Distribution	$1.13	$0.37	**$1.89**	$3.39
SMR Central Liquid Distribution	$1.13	$0.37	**$2.54**	$4.04
Coal Central No Sequestration Pipeline Distribution	$0.26	$0.99	**$1.75**	$3.00
Coal Central No Sequestration Liquid Distribution	$0.26	$0.99	**$1.75**	$3.00
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	**$1.89**	$7.92
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	**$2.54**	$8.57

Apply New Delivery Goals

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	$0.70	$0.87	**$1.75**	$3.32
Biomass Central Liquid Distribution	$0.70	$0.87	**$1.75**	$3.32
SMR Central Pipeline Distribution	$1.13	$0.37	**$1.75**	$3.25
SMR Central Liquid Distribution	$1.13	$0.37	**$1.75**	$3.25
Coal Central No Sequestration Pipeline Distribution	$0.26	$0.99	**$1.75**	$3.00
Coal Central No Sequestration Liquid Distribution	$0.26	$0.99	**$1.75**	$3.00
Central Wind Electrolysis Pipeline Distribution	$0.01	$6.03	**$1.75**	$7.79
Central Wind Electrolysis Liquid Distribution	$0.01	$6.03	**$1.75**	$7.79

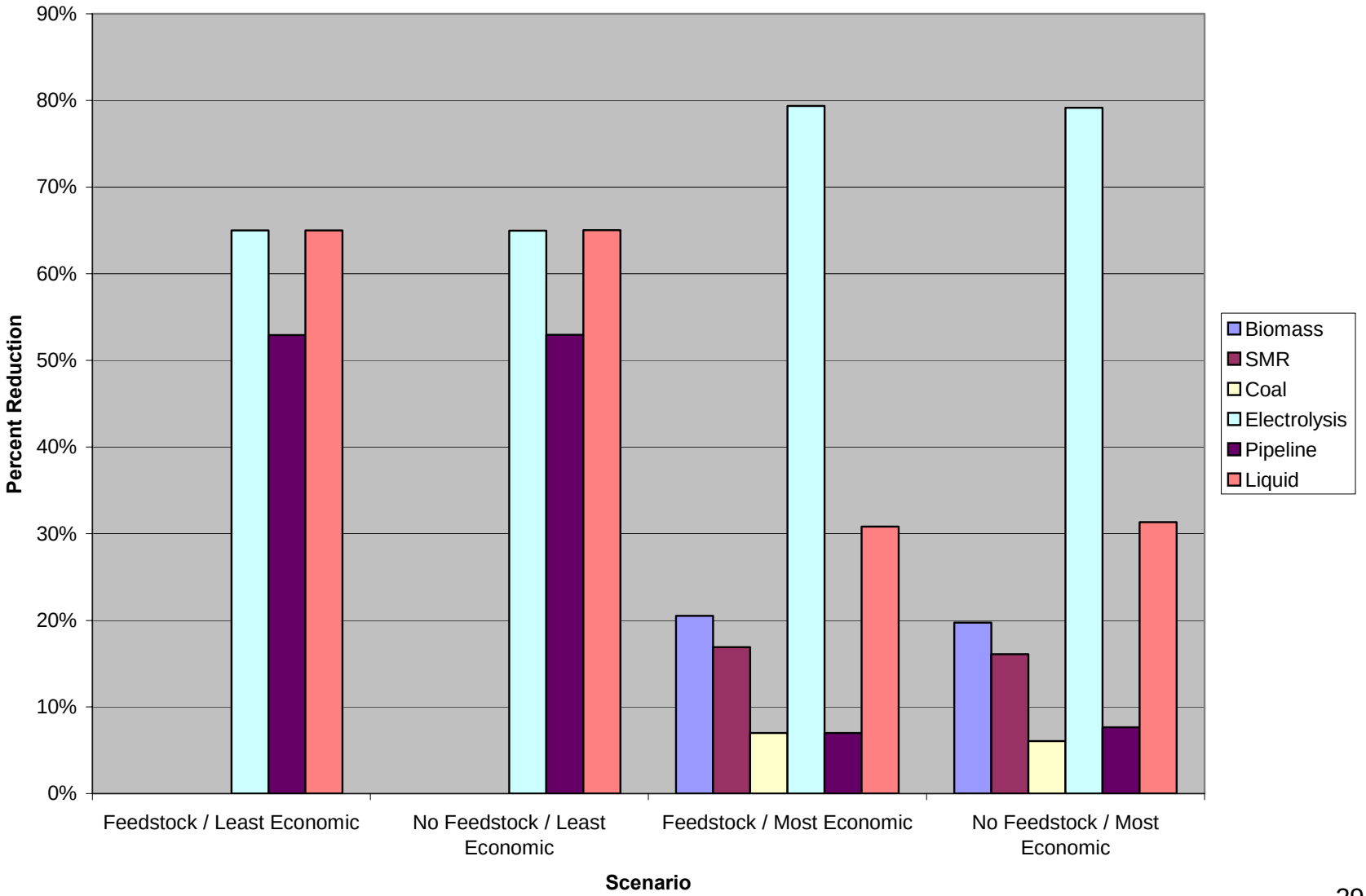
Normalize Production Goals

	Feedstock	Production	Delivery	Total Delivered Hydrogen Cost
Biomass Central Pipeline Distribution	**$0.55**	**$0.69**	$1.75	**$3.00**
Biomass Central Liquid Distribution	**$0.55**	**$0.69**	$1.75	**$3.00**
SMR Central Pipeline Distribution	**$0.94**	**$0.30**	$1.75	**$3.00**
SMR Central Liquid Distribution	**$0.94**	**$0.30**	$1.75	**$3.00**
Coal Central No Sequestration Pipeline Distribution	$0.26	$0.99	$1.75	$3.00
Coal Central No Sequestration Liquid Distribution	$0.26	$0.99	$1.75	$3.00
Central Wind Electrolysis Pipeline Distribution	**$0.00**	**$1.24**	$1.75	**$3.00**
Central Wind Electrolysis Liquid Distribution	**$0.00**	**$1.24**	$1.75	**$3.00**

Comparison

- “Least Economic” Basis
  - Obtains greatest cost reductions from delivery components
  - All pathways except electrolysis below threshold goal, but above prioritization goal
- “Most Economic” Basis
  - Balances cost reductions between production and delivery
  - All pathways meet threshold goal

Component Cost Reductions



Results: Biomass

Pathway Component	Biomass Gasification 2015 MYPP Targets	Goals
Feedstock	$0.5/gge	$0.55-0.70/gge
Production (Capital, fixed cost, variable cost, ex feedstock)	$1.10/gge	$0.56-0.86/gge
Delivery	$1.00/gge	$0.89-1.75/gge
Total	$2.60/gge	$2.45-3.00/gge

Notes:

1. The MYPP refers to the Hydrogen Program Multi-Year Research and Production Plan for the respective technology.
2. The Delivery cost for the Pathway Component Goals is a sum of the Transport and Forecourt costs from the Pathway Component Goal Methodology.

Results: Wind Electrolysis

Pathway Component	Wind Electrolysis 2015 MYPP Targets	Goals
Feedstock	$0.01/gge	$0.00-0.01/gge
Production (Capital, fixed cost, variable cost, ex feedstock)	$1.70/gge	$1.24-2.11/gge
Delivery	$1.00/gge	$0.89-1.75/gge
Total	$2.71/gge	$3.00/gge

Notes:

1. The MYPP refers to the Hydrogen Program Multi-Year Research and Production Plan for the respective technology.
2. The Delivery cost for the Pathway Component Goals is a sum of the Transport and Forecourt costs from the Pathway Component Goal Methodology.

Discussion Process

- FPITT component goals are intended to start the discussion
- Technical feasibility should be evaluated by the other Tech Teams
- FPITT will engage the other Tech Teams in the discussion
- Other Approaches?
  - Timing/simultaneous maturity
  - Changes in granularity
  - Do all pathways need to “succeed”?

Summary

- FPITT has developed a set of component goals that are consistent with the pathway-independent goal, both numerically and philosophically
- Discussion of these goals vs. current goals and technical feasibility can now begin, with the aim of confirming or changing the current goals